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March 17, 2000

03/11 U.S. PTO  
09/52862  
03/17/00

Assistant Commissioner for Patents  
Box Patent Application  
Washington, D.C. 20231

Re: MULTI ELEMENT, MULTI COLOR SOLID STATE LED/LASER  
Docket No. 585-27-009

Sir:

Transmitted herewith for filing under 35 U.S.C. 111 and 37 CFR 1.53 is the patent application of STEVEN P. DENBAARS, ERIC J. TARSA, MICHAEL MACK, BERND KELLER and BRIAN THIBEAULT entitled MULTI ELEMENT, MULTI COLOR SOLID STATE LED/LASER.

Enclosed are:

21 pages of written description, claims and abstract.  
4 sheets of drawings plus 2 copies.  
An Assignment of the invention to NITRES, INC.  
Executed Declaration and Power of Attorney.  
Verified Statement Claiming Small Entity Status.

The filing and recording fees have been calculated as shown below:

Basic Fee				\$345.00	
Total Claims	(29- 20)	x	\$9.00	=	81.00
Independent Claims	(2 - 3 )	x	\$39.00	=	0.00
Assignment Recording Fee					40.00
			Total Fee:		\$466.00

Our Check No 14664 for \$466.00 to cover the filing and recording fees is enclosed. We authorize the Commissioner to charge (1) payment of any additional filing fees required under 37 CFR §1.16, (2) payment of any patent application processing fees under 37 CFR §1.17 associated with this communication, or (3) payment of any fees that occur during the pendency of this application (and to credit any overpayment) to Deposit Account No. 11-1580. We enclose a duplicate copy of this sheet.

Very truly yours,  
KOPPEL & JACOBS

  
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JGH/mm  
Enclosures  
M12-585-27-009Transmittal ltr.doc

## IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inventors: STEVEN P. DENBAARS, ERIC TARSA, MICHAEL MACK, BERND KELLER  
AND BRIAN THIBEAULT

Title: MULTIPLE ELEMENT, MULTIPLE COLOR SOLID STATE LED/LASER

VERIFIED STATEMENT CLAIMING SMALL ENTITY STATUS

I, FRED BLUM, declare: I am the Chief Executive Officer of NITRES, INC. and am authorized to make this Statement. NITRES, INC. qualifies as a small business concern as defined in 13 C.F.R. §121.3-18, and reproduced in 37 C.F.R. §1.9(d), for purposes of paying reduced fees under 35 U.S.C. §41(a) and (b), in that the number of employees of the concern, including those of its affiliates, does not exceed 500 persons. For purposes of this statement, (1) the number of employees of the business concern is the average, over the previous fiscal year of the concern, of the persons employed on a full-time, part-time or temporary basis during each of the pay periods of the fiscal year, and (2) concerns are affiliates of each other when either, directly or indirectly, one concern controls or has the power to control the other, or a third party or parties controls or has the power to control both.

All rights under contract or law have been conveyed to and remain with NITRES, INC. with regard to the invention entitled "MULTIPLE ELEMENT, MULTIPLE COLOR SOLID STATE LED/LASER", which is Docket No. 585-27-009 in the files of NITRES, INC. 's lawyers KOPPEL & JACOBS. The application is filed with this Statement.

NITRES, INC. acknowledges the duty to file, in this application or the patent issuing on this application, notification of any change in status resulting in loss of entitlement to small entity status before paying, or at the time of paying, the earliest of the issue fee or any maintenance fee which is due after the date on which status as a small entity is no longer appropriate. (37 C.F.R. §1.28(b)).

I declare further that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true. These statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001, and that such willful false statements may jeopardize the validity of the application or any patent issuing from this application.

Date: 12/27/99

  
\_\_\_\_\_  
FRED BLUM  
Chief Executive Officer  
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107 South La Patera Lane  
Goleta, California 93117

**DECLARATION, POWER OF ATTORNEY AND  
STATEMENT CLAIMING SMALL ENTITY STATUS**

We, Steven P. DenBaars, Eric J. Tarsa, Michael Mack, Bernd Keller and Brian Thibeault, declare: We are citizens of the United States of America, residing at Goleta, California; Goleta, California; Santa Barbara, California; Goleta California and Santa Barbara, California, respectively. We believe we are the original, first and joint inventors of the invention entitled "MULTIPLE ELEMENT, MULTIPLE COLOR SOLID STATE LED" described and claimed in the attached specification. We have reviewed and understand the contents of the specification, including the claims. We acknowledge a duty to disclose information of which we are aware that is material to the examination of this application in accordance with 37 C.F.R. §1.56(a).

**SMALL ENTITY STATUS STATEMENT**

We further declare that we qualify as independent inventors as defined in 37 C.F.R. §1.9(c) for purposes of paying reduced fees under 35 U.S.C. §§41(a) and (b) to the Patent and Trademark Office with regard to this invention.

We have not assigned, granted, conveyed or licensed and am under no obligation under contract or law to assign, grant, convey or license, any rights in the invention to any person who could not be classified as an independent inventor under 37 C.F.R. §1.9(c) if that person had made the invention, or to any concern which would not qualify as a small business concern under 37 C.F.R. §1.9(e).

We acknowledge the duty to file, in this application or the patent issuing on this application, notification of any change in status resulting in loss of entitlement to small entity status before paying or at the time of paying the earliest of: (1) the issue fee or (2) any maintenance fee, which is due after the date on which status as a small entity is no longer appropriate. (37 C.F.R. §1.28(b))

We declare further that all statements made herein of our own knowledge are true and that all statements made on information and belief are believed to be true. These statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. §1001, and that such willful false statements may jeopardize the validity of this application or any patent issuing from this application.

**POWER OF ATTORNEY**

We hereby appoint Jaye G. Heybl (Reg. No. 42,661) and Richard S. Koppel (Reg. No. 26,475) and whose address is:

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my attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected with the application.

Wherefore, we subscribe our names to the foregoing specification, claims and declaration.

Date: 12-28, 1999

  
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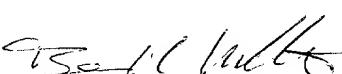
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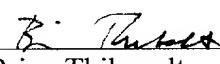
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APPLICATION

OF

STEVEN P. DENBAARS, ERIC J. TARSA, MICHAEL MACK,  
BERND KELLER and BRIAN THIBEAULT

FOR

UNITED STATES LETTERS PATENT

ON

MULTI ELEMENT, MULTI COLOR SOLID STATE LED/LASER

Docket No. 585-27-009

**Assigned to**

NITRES, INC.

**MULTI ELEMENT, MULTI COLOR SOLID STATE LED/LASER**

The following application is a utility application for provisional application number 60/166,444 to Denbaars et al., which was filed on November 19, 1999.

**BACKGROUND OF THE INVENTION****Field of the Invention**

5 This invention relates to solid state light emitting diodes (LEDs) and lasers that can emit various colors of light, including white.

**Description of the Related Art**

10 Light emitting diodes (LEDs) are an important class of solid state devices that convert electric energy to light. They generally comprise one or more active layers of semiconductor material sandwiched between oppositely doped layers. When a bias is applied across the doped layers, holes and electrons are injected into the active layer 15 where they recombine to generate light. Light is emitted omnidirectionally from the active layer and from all surfaces of the LED. The useful light is generally emitted in the direction of the LED's top surface, which is usually p-type.

20 One disadvantage of conventional LEDs is that they cannot generate white light from their active layers. One way to produce white light from conventional LEDs is to combine different colors from different LEDs. For example, the light from red, green and blue LEDs, or blue and yellow 25 LEDs can be combined to produce white light. One disadvantage of this approach is that it requires the use of multiple LEDs to produce a single color of light, increasing costs. In addition, different colors of light are often generated from different types of LEDs which can

5 require complex fabrication to combine in one device. The resulting devices can also require complicated control electronics since the different diode types can require different control voltages. Long term wavelength and stability of these devices is also degraded by the different aging behavior of the different LEDs.

10 More recently, the light from a single blue emitting LED has been converted to white light by surrounding the LED with a yellow phosphor, polymer or dye. [See Nichia Corp. white LED, Part No. NSPW300BS, NSPW312BS, etc., which comprise blue LEDs surrounded by a yellow phosphor powder.; see also U.S. Patent No. 5959316 to Hayden, entitled 15 Multiple Encapsulation of Phosphor-LED Devices.] The surrounding material "downconverts" the wavelength of some of the LED light, changing its color. For example, if a 20 nitride based blue emitting LED is surrounded by a yellow phosphor, some of the blue light will pass through the phosphor without being changed while the remaining light will be downconverted to yellow. The LED will emit both blue and yellow light, which combine to produce white light.

25 However, the addition of the phosphor results in a more complex LED that requires a more complex manufacturing process. In addition, the net light emitting efficiency is reduced due to the absorption in the phosphor and the 30 stokes shift from blue to yellow. Other examples of LEDs using this approach include U.S. Patent No. 5,813,753 to Vriens et al., and U.S. Patent No. 5,959,316 to Lowery.

35 Another disadvantage of most conventional LEDs is that they are less efficient at converting current to light compared to filament lights. However, recent advances in nitride based LEDs have resulted in highly efficient blue light sources, and their efficiency is expected to surpass filament (and flourescent) based light sources. However, conventional blue LEDs operate from a relatively low supply

current that results is a light that is too dim for many lighting applications. This problem is compounded by the absorption of some of the blue light by the downconverting material used to generating white light from blue. For 5 blue LEDs to provide a bright enough light source for room illumination, the current applied to the LED must be increased from the conventional 20-60 mAmps to 0.8-1 Amp. At this current, LEDs become very hot and any material surrounding the LED will also become hot. The heat can 10 damage the downconverting material surrounding the LED, degrading its ability to downconvert the LED's light. The heat can also present a danger of burning objects that are near or in contact with the LED.

15 Another disadvantage of conventional LEDs is that they only emit one color of light. In conventional multi-color LED displays, different LEDs must be included to generate different colors of light. In applications such as displays or television screens, this can result in a prohibitive number of LEDs and can require complex control electronics.

20 Solid state lasers convert electrical energy to light in much the same way as LEDs. [Prentice Hall, Laser Electronics 2<sup>nd</sup> Edition, J.T. Verdeyen, Page 363 (1989)]. They are structurally similar to LEDs but have mirrors on two opposing surfaces. In the case or edge emitting lasers 25 the mirrors are on the device's side surfaces and reflect light generated by the active layer until it reaches a high enough energy level to escape from the side of the laser, through one of the mirrors. This results in a highly collimated/coherent light source. A vertical cavity laser works much the same as an edge emitting laser, but the 30 mirrors are on the top and the bottom. Light from the active layer reflects between the mirrors until it reaches a stimulated emission level, providing a similar collimated light source from the laser's top surface.

35 However, conventional solid state lasers cannot efficiently emit green and blue light. Red emitting solid

state lasers are more common, but their performance degrades with temperature and if the temperature reaches a high enough point, the laser will stop emitting light.

5 SUMMARY OF THE INVENTION

The present invention provides new LEDs and solid state lasers that are grown on substrates doped with one or more rare earth or transition elements. The new LED/lasers rely on the light absorption and emission properties of the 10 doped substrate to produce new colors of light. In LEDs having multiple emitting layers or substrates doped with more than one element, the supply current can be manipulated such that a single LED can produce more than one color. One particular advantage of the invention is 15 that it provides a new white light emitting LED.

The new LED can have one or more active layers that emit light omnidirectionally, with some of the light emitting from the LED's surface and some of it passing into its doped substrate. Depending on the type of substrate and dopant, the substrate will absorb light within a 20 limited range of wavelengths. A light within this absorption range pumps the electrons on the dopant ions to a higher energy state. The pumped electrons are drawn back to their natural equilibrium state and emit energy as light 25 at a wavelength that depends upon the type of dopant ion. Light is emitted omnidirectionally, including through the surface of the LED. The wavelength of light emitted from the dopant ion will be different than emitted by the active layers, effectively changing the color of light emitted 30 from the overall device.

The new LED can have one or more active layers, and is 35 preferably made of Al-Ga-In-N ("nitride") based semiconductor materials. The LED is grown on a sapphire substrate that is doped by one of the rare earth or transition elements, such as chromium (Cr). Doping sapphire with CR creates ruby which is particularly useful

as a substrate for nitride based LEDs. Ruby absorbs ultraviolet (UV) light with a wavelength of about 400-420 nanometers (nm), which can be efficiently emitted by nitride based LEDs. The energy from the absorbed light 5 pumps the electrons of the Cr ion to a higher energy state and as the electrons return to their equilibrium state, they emit energy as red light. The light is emitted omnidirectionally with some of it emitting from the surface of the LED along with the active layer's UV light. The UV 10 light will not be visible to the eye and, as a result, the new LED will appear as though it is emitting red light.

The new LED can also have multiple active layers which emit different wavelengths of light. In one embodiment, the LED is grown on a ruby substrate and has active layers 15 which produce green light, blue light, and UV light. The substrate will not absorb the green or blue light, but will absorb the UV light and emit red light omnidirectionally as the pumped dopant ions return to equilibrium. Green, blue, and red light will emit from the surface of the LED and 20 will combine to produce a white light. Because this embodiment does not use conversion materials, it can operate at elevated current levels.

Another important advantage of the new multiple active 25 layer LED is that, if desired, the active layers can be excited individually or in combination. This allows the new LED to be "tunable" and emit different colors by manipulating the current applied to the various active layers. The new LED can emit green, blue, or red if only 30 one of the active layers are excited, or it can emit purple, aqua, or yellow if two of the active layers are excited.

As the level of current is increased across an active 35 layer, it will emit brighter light. Accordingly, the level of current applied to each active layer can also be manipulated to vary the color emitting from the LED.

The doped substrate approach can also be used in solid

state lasers to more efficiently produce blue and green light. By doping a sapphire substrate with cobalt (Co), UV light from the lasers active layer that enters the substrate will be absorbed and re-emitted as green light 5 for stimulated emission.

The invention can be used to create more temperature 10 resistant red lasers. In one embodiment, the laser can be nitride based and emit UV light from its active layer. The laser can be grown on a ruby substrate which emits red light in response to absorbed UV light. Both UV and red 15 light will emit from the laser but it will appear as though only red light is being emitted. Different types of lasers emitting different colors of light can also be made.

These and other further features and advantages of the 15 invention will be apparent to those skilled in the art from the following detailed description, taken together with the accompanying drawings, in which:

#### BRIEF DESCRIPTION OF THE DRAWINGS

20 FIG. 1 is a sectional view of a new LED grown on a ruby substrate and having a UV emitting active layer;

FIG. 2 is a sectional view of a new LED grown on a ruby substrate and having multiple active layers;

25 FIG. 3 is a sectional view of a new LED grown on a sapphire substrate doped with multiple elements, and having a UV emitting multiple quantum well active layer;

FIG. 4 is a sectional view of a new LED grown on a ruby substrate, and having a blue and yellow emitting multiple quantum well active layer;

30 FIG. 5 is a sectional view of a new LED grown on a sapphire substrate having doped color centers, and having a multiple quantum will active layer;

35 FIG. 6 is a sectional view of new LED grown on a ruby substrate and having two active layers, one of which is partially surrounded by a downconverting material;

FIG. 7 is a sectional view of a nitride based edge

emitting solid state laser, grown on a doped substrate; and

FIG. 8 is a sectional view of a nitride based top emitting solid state laser grown on a doped substrate.

FIG. 9 is a block diagram of the new LED/laser,  
5 connected to electrical circuitry.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1 shows a single active layer nitride based LED  
10 constructed in accordance with the invention. It has an  
InGaN active layer 11 which emits UV light, sandwiched  
between two oppositely doped GaN layers 12 and 13. The top  
layer 12 is usually p-type GaN and bottom layer 13 is  
usually n-type GaN although the new LED would also work if  
the layers were reversed. The p-type layer and n-type  
15 layers have respective contacts 14 and 15, each having a  
lead to apply a bias across the active layer 11, causing it  
to emit light omnidirectionally. The entire LED is grown  
on a sapphire ( $\text{Al}_2\text{O}_3$ ) substrate doped with chromium (Cr),  
which creates ruby. Ruby is commercially available from  
20 companies such as Union Carbide in a form that can be used  
for substrates on solid state devices. The LED can be grown  
on the substrate by many known methods with the preferred  
method being Metal Organic Chemical Vapor Deposition  
(MOCVD).

25 Some of the light emitted from active layer 11 will  
pass through its top surface and some will pass into the  
ruby substrate 16. The UV light emitted from the top  
surface will not be visible. Some or all of the light  
passing into the substrate 16 will be absorbed, pumping the  
30 substrate's Cr electrons to a higher energy state. As the  
electrons return to their equilibrium state, they emit  
energy as red light at a wavelength of about 630nm. This  
light will emit omnidirectionally, including through the  
top surface of the LED. Because the UV light is not  
35 visible, the new LED will appear as though it is only  
emitting red light. Thus, the new LED provides red light

without external conversion materials and without being combined with other colors or types of LEDs.

Ruby substrates also absorb yellow light at a wavelength of about 550nm and, as the dopant electrons return to their equilibrium state, they emit red light. A nitride based LED can have an active layer made of AlGaN that emits yellow light having a wavelength of about 550nm. Some of the light will pass into the ruby substrate and stimulate an emission of red light. Both yellow from the active layer and red light from the substrate will be emit from the LED's surface.

This new technique for producing different colors of LED light by doping their substrates can be used in light emitting devices made of many different material systems. The devices can have one or more active layers that can be double heterostructure, single quantum well, or multiple quantum well. The substrate can be made of many different materials other that sapphire, including but not limited to spinel, silicon carbide, gallium nitride, quartz YAGI, garnet, or oxide single crystal. It can also be made of other oxide materials such as lithium gallate, lithium niobate, or zinc oxide.

The substrate dopant can be many different rare earth or transition elements other than Cr, including but not limited to cobalt, titanium, iron, magnesium, nickel, erbium, neodymium, praseodymium, europium, thulium, ytterbium, or cerium. The different dopant and substrates will work like the ruby substrate, absorbing certain wavelengths of light and emitting different wavelengths of light when the pumped dopant ion electrons return to their equilibrium state. For example, if a sapphire substrate is doped with nickel or magnesium it will absorb UV light and emit green light. If a sapphire substrate is doped with iron or titanium, it will absorb UV and emit blue light. If doped with cobalt, it will absorb UV light and emit green light. The substrate can also use polymers that function

much the same as the rare earth and transition element dopants.

The substrate 16 can be doped with the desired rare earth or transition element by many doping methods. The 5 preferred methods include solid state diffusion, ion implantation, beam evaporation, sputtering, or laser doping

FIG. 2 shows another embodiment of the new LED 20 which is nitride based and has three active layers 21, 22 and 23, each of which emits a different wavelength of 10 light. This allows the LED 20 to emit multiple colors that combine to produce white light. The active layers 21, 22 and 23 are composed of InGaN in different percentages such 15 that they respectively emit green, blue and UV light with respective wavelengths of about 520nm, 470nm and 400 to 420nm. Examples of the different percentages of In necessary in the active layer to produce various colors of 20 light include: 0 percent (%) for UV Light, 5 to 10% for near UV light, 10 to 27% for blue light, 28 to 35% for green light, and 35 to 60% for yellow light.

The LED 20 has three p-type layers 24, 25 and 26, all 25 made of GaN. P-type layer 24 is adjacent to active layer 21 and injects holes into the active layer 21 when a bias is applied to its contact 27. Similarly, p-type layer 25 injects holes into active layer 22 when a bias is applied to its contact 28, and p-type layer 26 injects holes into active layer 23 when a bias is applied to its contact 29. The n-type layer 30 is also made of GaN and is used to 30 inject electrons into all active layers when a bias is applied to its contact 31, with the electrons migrating into each active layer 21, 22 and 23. The entire device is grown on a ruby substrate 32.

With a bias applied across the n-type contact 31 and 35 all p-type contacts 27, 28, and 29 (usually in the range of 3 to 4 volts), each of the active layers 21, 22 and 23 will emit light omnidirectionally. Green, blue and UV light will be emit through the surface of the LED 20 and will also

5 pass into the ruby substrate 32. The Cr in the substrate 32 will only absorb the UV light and as the Cr electrons return to their equilibrium state, they will emit red light. Some of the red light will emit from the LED's 10 surface along with the green, blue, and UV light, all of which will combine to produce white light.

10 Another advantage of the new LED 20 is that a bias can be applied to one or more of the p-type contacts 27, 28, and 29, which allows the LED 20 to selectively emit 15 different colors of light. For example, with a bias applied to p-type contact 27 and n-type contact 31, holes and electrons are primarily injected into active layer 21 and it emits green light. The light will not be absorbed by the ruby substrate and as a result, the LED 20 only emits green 20 light. Similarly, with a bias applied to p-type contact 28 and n-type contact 31, the LED 20 emits only blue light. With a bias applied to p-type contact 29 and n-type contact 31, active layer 23 emits UV light that the ruby substrate absorbs and re-emits as red light. Thus, by applying a bias 25 to one of the three p-type contacts 27, 28, and 29, the LED 20 can selectively emit green, blue, or red light.

25 With a bias applied to across the n-type contact 31 and two of the three p-type contacts 27, 28 and 29, two colors of light emit from the LED 20 that combine to produce additional colors. With a bias applied to contacts 27 and 28, green and blue light emit and combine to produce 30 aqua. With a bias applied to contacts 27 and 29, green and red light emit and combine to produce yellow. With a bias applied to contacts 28 and 29, blue and red light emit to produce purple.

35 The brightness of light emitted from the various active layers is dependant upon the level of current that is applied to the respective contacts; the greater the current, the brighter the light and vice versa. Increasing or decreasing the level of the current to the active layers 21, 22, and 23, can produce variations in the colors of

light emitted from the LED 20. For example, with a standard current applied to the blue active layer 22, and an increased current applied to the green active layer 21, the aqua emitted by the LED 20 would have more green 5 compared to the aqua emitted if both active layers 21 and 22 received a normal current. This allows even greater flexibility in the colors of light emitted from the LED 20.

White light can also be produced by a new LED generating only one color of light from its active layer, 10 by doping the substrate with more than one rare earth or transition element. FIG. 3 shows another embodiment of the new LED 34 being nitride based and having a UV emitting multiple quantum well active layer 35 made of InGaN, although other types of active layers can also be used. It 15 is sandwiched between a GaN n-type layer 36 and a GaN p-type layer 37. When a bias is applied across the p-type contact 39 and n-type contact 40, the active layer 35 will emit UV light with some of it emitting from the LED surface and some of it passing into the substrate 38. The 20 substrate 38 is doped with Cr which absorbs UV light and emits red light, Titanium (Ti) which absorbs UV light and emits blue light, and Cobalt (Co) which absorbs UV light and emits green light. The red, green, and blue light will be emitted from the substrate omnidirectionally, with some 25 of it emitting from the LED's surface to produce white light.

FIG. 4 shows another embodiment of the new LED 44 with an InGaN multiple quantum well active layer 45, although other types of active layers can also be used. The active 30 layer 45 emits blue light with a wavelength of about 470nm and yellow light with a wavelength of about 550nm. The LED 44 has a AlGaN layer 46 on top of the active layer 45 with a p-type GaN layer 47 on top of the AlGaN layer 46. It also has an n-type GaN layer 48 below the active layer 45. A 35 bias is applied across the active layer 45 through a p-type contact 49 and an n-type contact 50. All of the LED layers

are grown on a ruby substrate 51.

When a bias is applied to the contacts 49 and 50, holes and electrons are injected into the active layer 45 which causes it to emit blue and yellow light. Some of the light emits from the surface of the LED 44 and some of it passes into the ruby substrate 51, which absorbs the yellow light and emits red light. The blue light will pass through the substrate 51 and will not be absorbed. Blue, yellow and red light will emit from surface of the LED 44 and combine to create a warm white light.

The new LED can also generate different colors of light by doping the substrate with "color centers" of various rare earth and transitional elements. The color centers consist of bodies of different doping materials within the substrate. FIG. 5 shows the new LED 52 grown on a substrate 53 which contains three color centers 59, 60 and 61. The LED comprises a multiple quantum well active layer 54 of InGaN which emits UV light. A p-type AlGaN layer 55 is grown on the active layer, a p-type GaN layer 56 is grown on the AlGaN layer 55, and an n-type GaN layer 57 is grown below the active layer 54. The entire LED 52 is grown on a sapphire substrate that has a Cr doped color center 59, a Ti doped color center 60, and a Co doped color center 61.

25 The LED 52 also includes an n-type contact 65 and  
three p-type contacts 62, 63, and 64, on the p-type layer  
56, each p-type contact above a respective color center. By  
manipulating the bias applied to the various contacts, the  
color emitted by the LED 52 can be changed. With a bias  
applied to the n-type contact 65 and p-type contact 62, the  
active layer 54 generates light primarily below the contact  
62 and the light from the active layer passes into the  
substrate 58 such that most of it passes into the Cr doped  
color center 59. Some or all of the light will be absorbed  
by the color center 59 and re-emitted as red light. With  
30 a bias instead applied to the p-type contact 63, the  
majority of light from the active layer enters the

substrate at the Ti doped color center 60 which absorbs some or all of the light and re-emits blue light. Finally, with a bias applied at the p-type contact 64, the majority of light enters the substrate at the Co color center which 5 absorbs some of the light and re-emits green light. Accordingly, by applying a bias across the n-type contact and one p-type contact, the LED 52 can selectively emit red, blue and green light.

Like the LED 20 in FIG. 2, a bias across the n-type contact 65 and more than one p-type contact 62, 63, and 64, creates different colors such as aqua, yellow, purple, and white. They are created by combining the colors from the different emitting color centers. The level of the current applied to the contacts can also be increased or decreased 10 to provide variations of the colors emitting from the LED 52. The greater the current applied to a p-type contact 59, 15 60 and 61, the greater the intensity of light emitted from the active layer 54 below the contact, and the greater the intensity of light absorbed and emitted from the color center below the contact. When the intensity of a 20 particular color is increased, it will be more dominant when combined with light from the other color centers.

FIG. 6 shows another embodiment of the new LED 65 that is partially surrounded by a YAG:Ce downconverting material 25 66. The LED 65 has an active layer 67 emitting blue light with a wavelength of about 470nm and an active layer 68 below it, emitting UV light having a wavelength of about 420nm. It also has two p-type layers 69 and 70 and an n-type layer 71 all of which have a respective contact 72, 30 73, and 74. The downconverting material 66 partially surrounds the top active layer 67 and it absorbs some of the blue light and downconverts it to yellow light. The LED is grown on a ruby substrate 75 that absorbs the UV light from the lower active layer 68 and re-emits red 35 light. As a result, the LED 65 emits blue, yellow and red light that combines to create white light.

Many other embodiments of the new LED can be constructed in accordance with the invention. The new LED can be grown on a ruby substrate and have three active layers, one emitting light with a wavelength of about 400-420nm, another emitting light with a wavelength of about 500nm and the last emitting light with a wavelength of about 550nm. Another embodiment can be grown on a ruby substrate and have three active layers, one emitting light with a wavelength of about 400-420nm, another emitting light with a wavelength of about 470nm and the last emitting light with a wavelength of about 520nm. The LED can also be grown on a ruby substrate and have two active layers, one emitting about 400-420nm light and the other emitting about 500nm light, or it can be grown on a ruby substrate and have two active regions one emitting about 500nm light and the other emitting about 550nm light.

The present invention can also be used with solid state laser such as edge emitting lasers and vertical cavity lasers. FIG. 7 shows an nitride based edge emitting laser 76 which is structurally similar to a LED. It has an InGaN active layer 77 sandwiched between a p-type GaN layer 78 and an n-type GaN layer 79, all of which are grown on a substrate 80 that is doped with Co. The laser 76 also has mirrors 81 and 82 to reflect light between the mirrors until the light reaches a sufficient energy level to escape through mirror 81, resulting in a highly collimated/coherent light source.

When a bias is applied to the p and n-type layers 78 and 79 through electrical contacts (not shown), the active layer 77 will emit light omnidirectionally and some of the light will pass into the substrate 80. Some or all of the light will be absorbed and will re-emit as green. The light will reflect between the mirrors 81 and 82 to produce stimulated LED emission of UV light and green light. The UV light will not be visible to the eye and as a result, the laser 76 will appear as though it is emitting green light.

Depending on the dopant used in the substrate 80, the color of the emitted light can be different, as described above. For example, the substrate can be doped with Cr such that it will absorb the UV light and emit red light. The new 5 red laser is more temperature tolerant compared to conventional red solid state lasers.

FIG. 8 shows a vertical cavity laser 83 which works much the same as an edge emitting laser and also has a doped substrate 84 and an UV emitting active layer 85 sandwiched between two oppositely doped layers 87 and 88. It has a mirror on its top surface 88 and its bottom 10 surface 89 and the collimated light is generally emitted through the top mirror 88. In operation, the light from the active layer 85 emits omnidirectionally and some of it will 15 reflect between the mirrors 88 and 89 to reach stimulated emission. Some of the light from the active layer 85 will also enter the substrate 84 where it will be absorbed and emit a different color depending on the dopant in the substrate. The light from the substrate 84 will also 20 reflect between the mirrors 88 and 89 and emit from the top surface as a collimated light. The UV light will not be visible and the laser will appear as though it is only emitting the wavelength of light from its substrate 84.

FIG. 9 shows the new LED/laser 90, connected to 25 electrical circuitry 91 that can perform various functions such as power conversion or conditioning. The circuitry can also control the biases applied to the various contacts on the LEDs described above, to control the colors the LEDs emit. In one embodiment, the electrical circuitry can be on 30 a common substrate 92 with the LED/laser 90.

Although the present invention has been described in 35 considerable detail with reference to certain preferred configurations thereof, other versions are possible. Therefore, the spirit and scope of the appended claims should not be limited to their preferred versions contained therein.

## WE CLAIM:

1. A solid state light emitting device, comprising:
  - an active layer;
  - 5 a pair of oppositely doped layers on opposite sides of said active layer which cause said active layer to emit light at a predetermined wavelength in response to an electrical bias across said doped layers; and
  - 10 a doped substrate, said active and doped layers disposed successively on said substrate such that said substrate absorbs at least some of said light from said active layer and re-emits light at a different wavelength.
2. The light emitting device of claim 1, comprising at least one said active layers and at least a pair of oppositely doped layers, said active layers between two oppositely doped layers which cause said active layers to emit light at a predetermined wavelength in response to a bias across said oppositely doped layers and said substrate absorbs at least some of said light from at least one of 15 said active layers and re-emits light at a different wavelength.
- 20 3. The light emitting device of claim 1, further comprising electrical contacts on each said oppositely doped layer to apply said bias across said oppositely doped layers.
- 25 4. The light emitting device of claim 1, wherein said active layers are multiple quantum wells, single quantum wells or double heterostructure.
- 30 5. The light emitting device of claim 1, wherein said substrate comprises sapphire, spinel, silicon carbide, gallium nitride, quartz YAGI, garnet, lithium gallate, lithium niobate, zinc oxide, or oxide single crystal.

6. The light emitting device of claim 1, wherein said substrate is doped with at least one rare earth or transition element.

5 7. The light emitting device of claim 1, wherein said sapphire is doped with at least one impurity such as chromium, titanium, iron, erbium, neodymium, praseodymium, europium, thulium, ytterbium or cerium.

10 8. The light emitting device of claim 1, comprising a light emitting diode (LED), said active layer emitting UV light and said substrate comprises sapphire doped with chromium, said substrate absorbing some of said UV light and re-emitting red light.

15 9. The light emitting device of claim 1, comprising a LED, said active layer emitting yellow light and said substrate comprises sapphire doped with chromium, said substrate absorbing some of said yellow light and re-emitting red light.

20 10. The light emitting device of claim 2, wherein the light emitting from said device comprises the light emitting from at least one of said active layers or the light emitting from at least one of said active layers in combination with the light emitted from said doped substrate.

25 11. The light emitting device of claim 2, comprising a LED, said active layers emitting blue, green and UV light and said substrate comprising sapphire doped with chromium which absorbs said UV light and re-emits red light, said LED emits blue, green, UV and red light when all said active layers are emitting, in a white light combination.

30 35 12. The light emitting device of claim 11, having three

active layers emitting blue, green and UV light, wherein each said active layer can selectively emit light, said LED emitting primarily red, green, or blue light when one of said active layer is emitting, or said LED emitting primarily purple, aqua, yellow, or white light when more than one said active layer is emitting.

13. The light emitting device of claim 2, comprising a LED, said active layers emitting blue and yellow light, said substrate doped with chromium such that it absorbs at least some of said yellow light and emits red light.

14. The light emitting device of claim 2, comprising a LED, said active layers emitting one color of light, said substrate doped throughout with more than one impurity such that said it absorbs said active layers, light and re-emit more than one color of light.

15. The light emitting device of claim 2, comprising a LED with at least one said active layer emitting UV light and said substrate doped throughout with chromium, titanium, iron, and cobalt, said doped substrate absorbs said UV light and emits red, green, and blue light.

25 16. The light emitting device of claim 2, comprising an LED with at least one said active layer emitting UV light, and said substrate doped by one or more rare earth or transition element in separate color centers that absorb UV light and re-emit a different color of light, said bias selectively applied to said active layers above said color centers causing said active layers to emit light that will be primarily absorbed by said color center below said active layers and re-emitted as a different color.

35 17. The light emitting device of claim 16, further comprising electrical contacts on said oppositely doped

layers to selectively apply said bias to said active layer above said color centers.

5 18. The light emitting device of claim 17, wherein said active layers emits UV light, and said substrate doped by one or more rare earth or transition element in separate color centers, each said color center absorbs UV light and re-emits it as a different color.

10 19. The light emitting device of claim 2, comprising a LED wherein said active layers emit blue light and UV light, said substrate absorbs at least some of said UV light and re-emits red light, said LED further comprising downconverting material around the surface of said LED that absorbs some of said blue light emitting from that surface and re-emits yellow light.

15 20. The light emitting device of claim 1, comprising a solid state laser and further comprising mirrors on opposing surfaces, both said light from said active layer and said light absorbed and re-emitted by said doped substrate reflected between said mirrors to achieve stimulated emission.

25 21. The light emitting device of claim 20, wherein said active layers emit UV light and said substrate is sapphire doped with cobalt, said laser providing stimulated emission of UV and green light.

30 22. The light emitting device of claim 20, wherein said active layers emit UV light and said substrate is sapphire doped with chromium, said laser providing stimulated emission of UV and red light.

35 23. The light emitting device of claim 1, further comprising electrical circuitry integrated with said device

on a common substrate.

24. The light emitting device of claim 1, wherein said doped substrate is doped using solid state diffusion, ion implantation, beam evaporation, sputtering, or laser doping.

25. A method for generating light from a solid state light emitting device, comprising:

10 exciting an optical emission from an active layer within a first wavelength range;

applying at least a portion of said optical emission to stimulate emission from a doped semiconductor material within a different wavelength range; and

15 transmitting both emissions.

26. The method of claim 25, wherein said doped semiconductor material comprises sapphire, spinel, silicon carbide, gallium nitride, quartz YAGI, garnet, lithium gallate, lithium niobate, zinc oxide, or oxide single crystal.

27. The method of claim 25, wherein said semiconductor material is doped with at least one rare earth or transition element.

28. The method of claim 25, wherein said semiconductor material is doped with at least one impurity from the group consisting of chromium, titanium, iron, erbium, neodymium, praseodymium, europium, thulium, ytterbium and/or cerium.

29. The method of claim 25, wherein said doped substrate is doped using solid state diffusion, ion implantation, beam evaporation, sputtering, or laser doping.

**ABSTRACT**

A light emitting diode (LED) grown on a substrate doped with one or more rare earth or transition element. The dopant ions absorb some or all of the light from the 5 LED's active layer, pumping the electrons on the dopant ion to a higher energy state. The electrons are naturally drawn to their equilibrium state and they emit light at a wavelength that depends on the type of dopant ion. The invention is particularly applicable to nitride based LEDs 10 emitting UV light and grown on a sapphire substrate doped with chromium. The chromium ions absorb the UV light, exciting the electrons on ions to a higher energy state. When they return to their equilibrium state they emit red 15 light and some of the red light will emit from the LED's surface. The LED can also have active layers that emit green and blue and UV light, such that the LED emits green, blue, red light and UV light which combines to create white light. Alternatively, it can have one active layer and 20 grown on a sapphire substrate doped with Cr, Ti, and Co such that the substrate absorbs the UV light and emits blue, green, and red light. The invention is also capable of providing a tunable LED over a variety of color shades. The invention is also applicable to solid state laser 25 having one or more active layers emitting UV light with the laser grown on a sapphire substrate doped with one or more rare earth or transition elements.



FIG.1

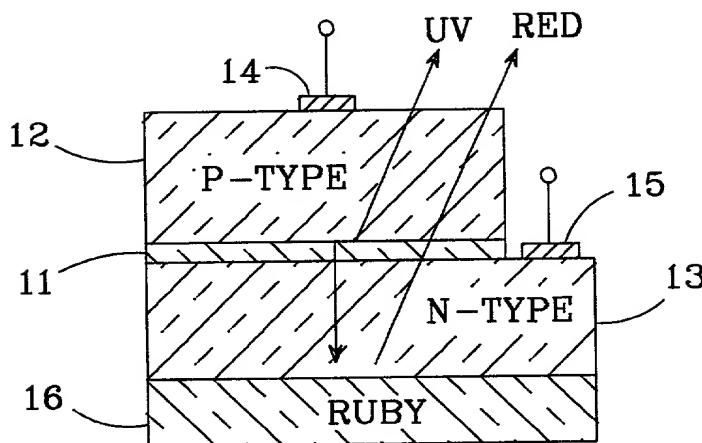


FIG.9

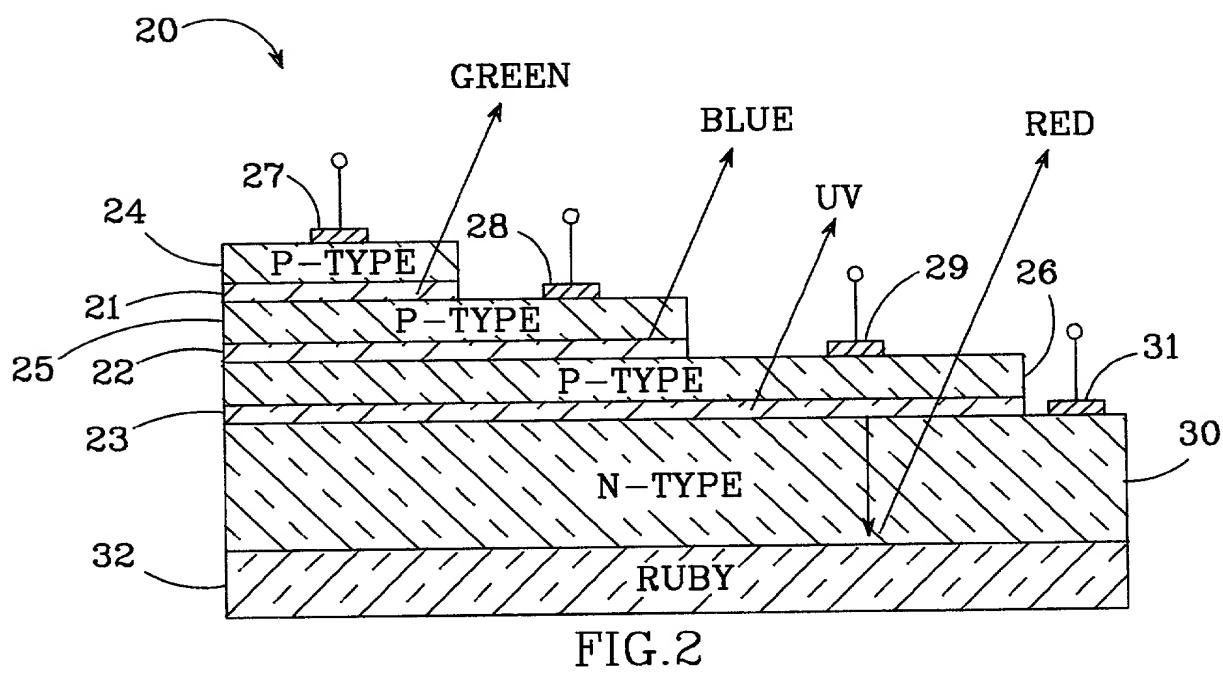
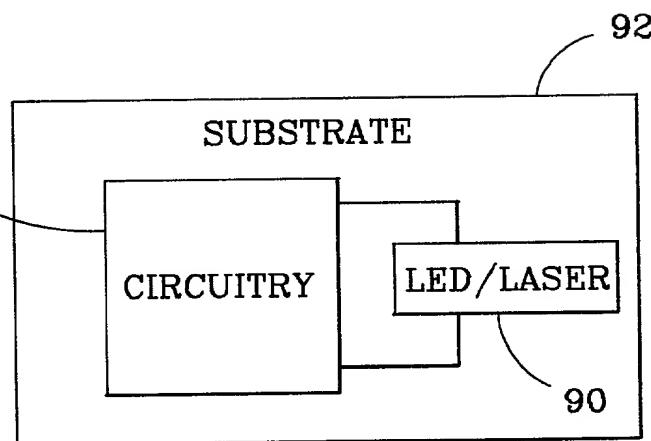


FIG.2

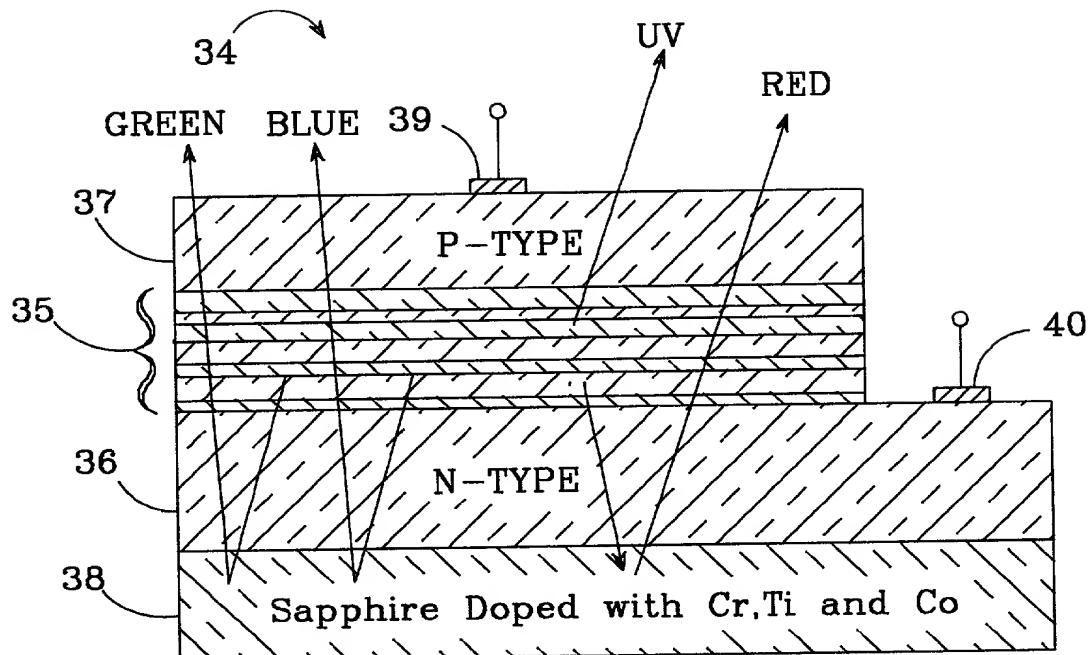


FIG.3

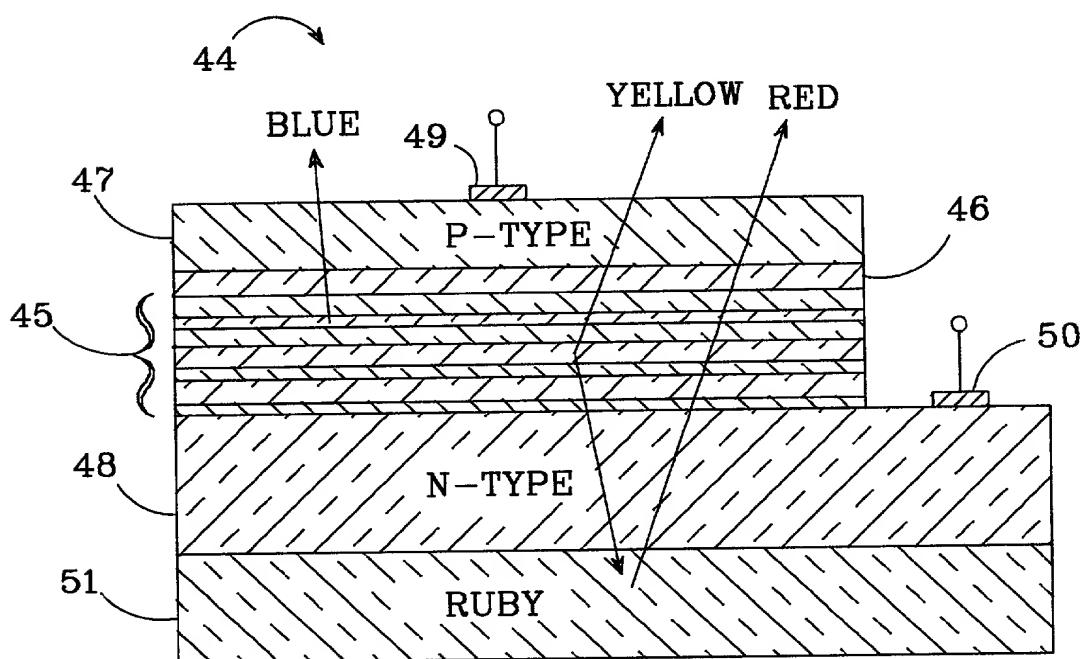
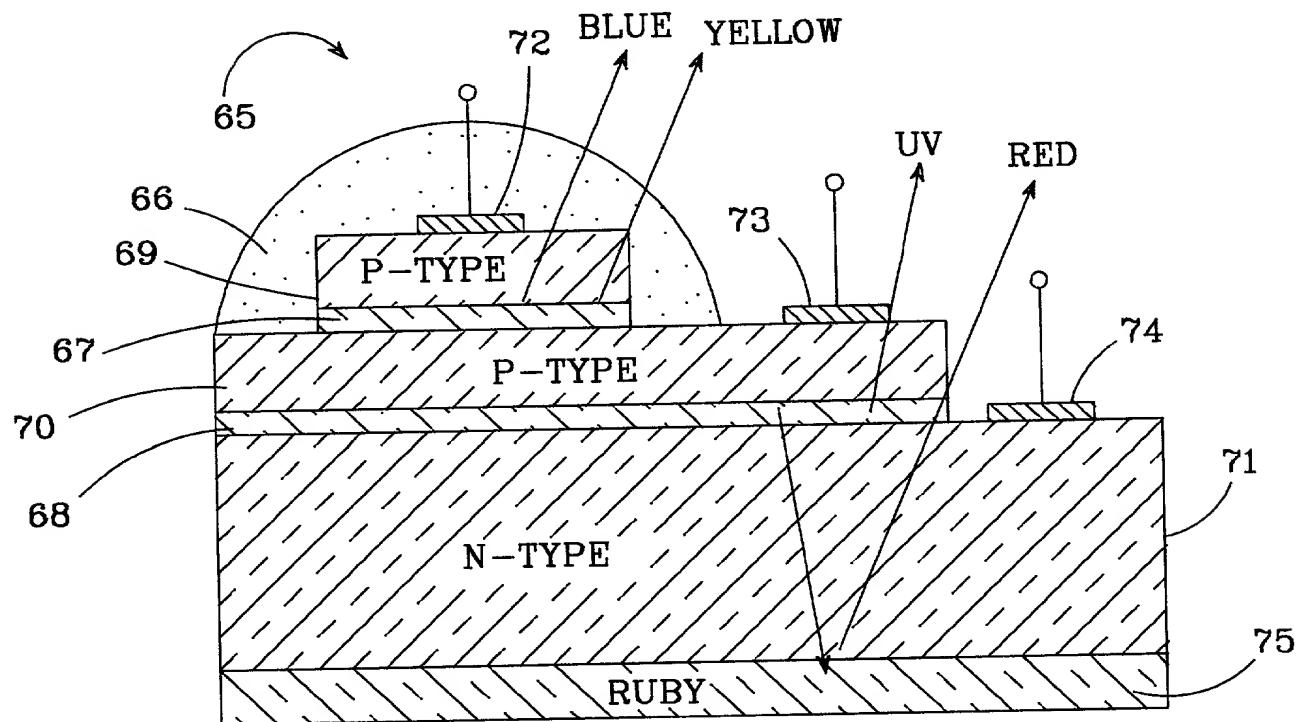
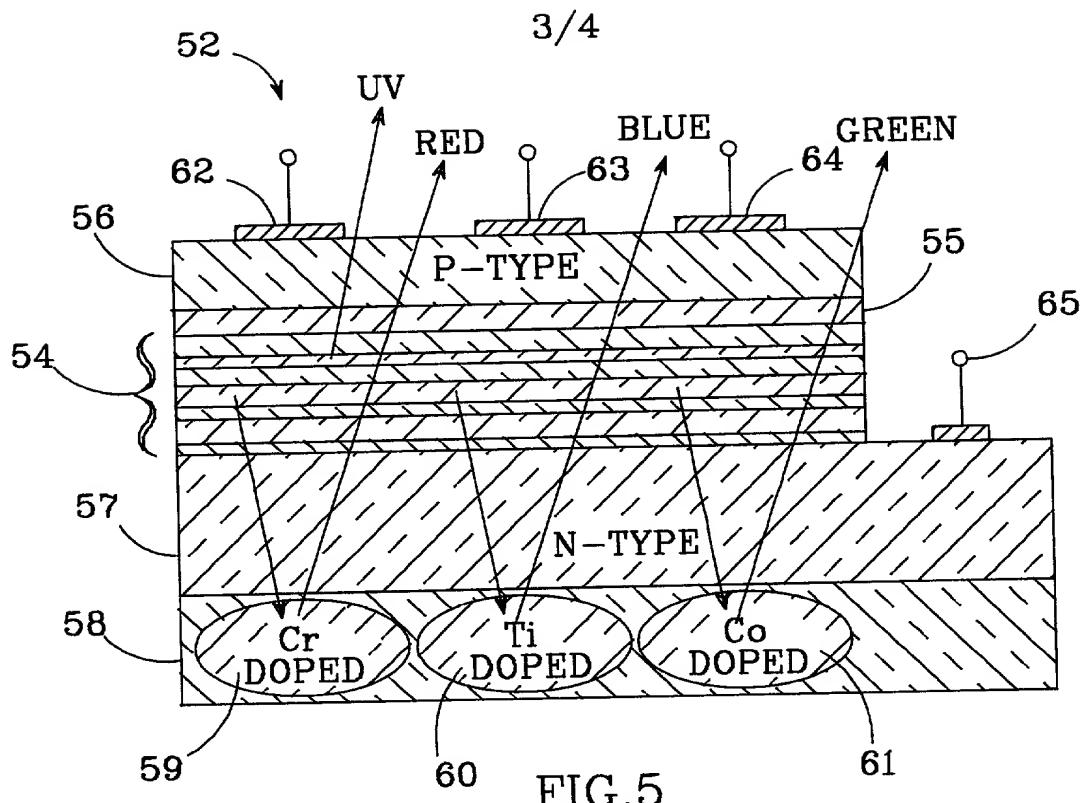


FIG.4



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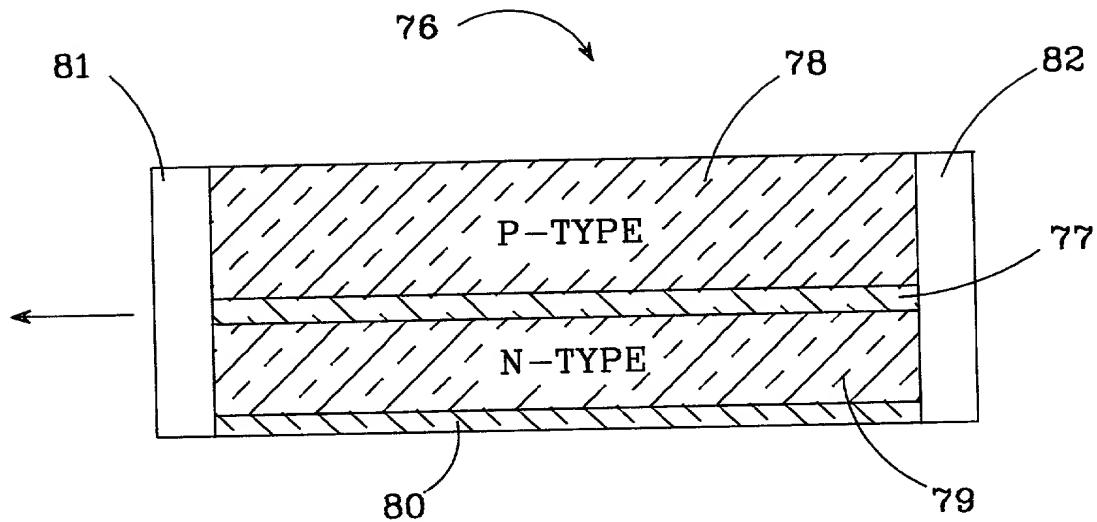


FIG.7

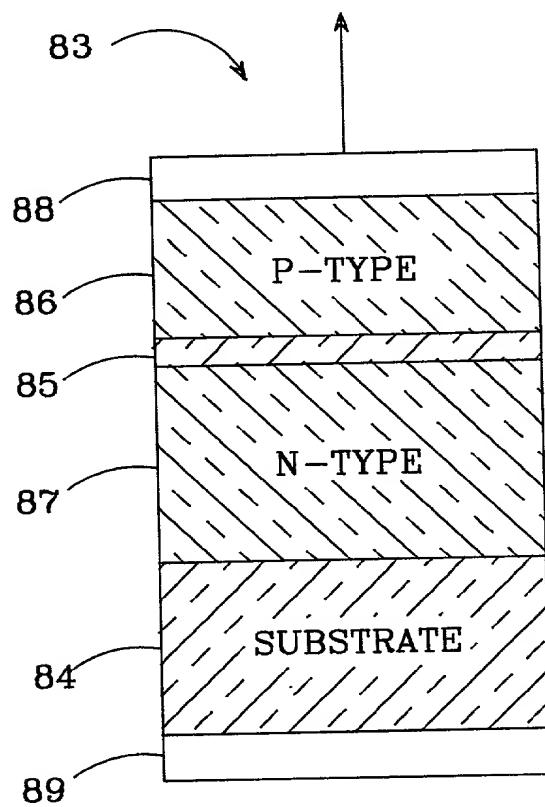


FIG.8